

Web-Based Simulations For Science and Math Instruction

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Pre-historic man simulated a hunt by throwing spears at a target. For the past 30 years, computer simulations have been developed to assist in education and training. Many instructional simulations are now available on the Web and more are sure to come over the following years.

Educational simulations provide interactive representations of reality. They allow students to test or discover how a phenomenon works, what affects it, and how it impacts other phenomena. The student is able to manipulate the model of reality and quickly discern the impacts of the manipulation. While most traditional instruction is aimed at helping students minimize their mistakes, most educational simulations are designed to have students make many mistakes and learn from them more quickly than would otherwise be possible.

Why Use Simulations

There are several advantages to Web-based simulations for the teaching of mathematics and science.

- They are more realistic than written exercises or descriptions of phenomena;
- They are more convenient to use than conducting actual experiments;
- They can accelerate exposure to a wide range of phenomena in a given amount of time and provide immediate feedback.
- They can eliminate dangers inherent in working with the real phenomena;
- They can slow down fast processes, such as those of a lightning strike, and they can speed up slow processes, such as those of the evolution of a species, so that both can be observed;
- They can simplify the complexity of a phenomenon that would initially overwhelm most students, and then gradually introduce it;
- They can initially provide some clues that would not be available when working directly with a phenomenon and then withdraw them gradually;
- They can allow students to stop the simulation at any point if they need time to think, to “rewind” the simulation when they have missed something, and to repeat the simulation when they want to try out other responses;
- They can motivate students who are bored with traditional classroom instruction and reading;

- They can cut the costs of many students conducting actual experiments in laboratories; and
- They can automatically record student responses for review by teachers and the developers of the simulation.

Simulations for the teaching of mathematics and science also have some disadvantages. These include:

- Simulations may over-simplify the phenomena to the point that the students do not gain a good understanding of them;
- They may inadvertently provide clues that allow students to reach high levels of performance with phenomena that they do not understand well;
- They may create a false sense of safety that could be dysfunctional when students move on to work directly with dangerous phenomena; and
- Some students may “game” the simulation, focusing on maximizing performance by means that would be ineffective, risky, or expensive in real experiments.

Forms of Simulations

Simulations can vary on several dimensions. Some simulations provide most of the information in text, describing a complex situation to which the student is to respond; others rely heavily on graphs, icons, and animation; still others use varying degrees of virtual reality. Many simulations are self-contained as initially developed. Some, however, download data that are collected by other sources such as a national weather bureau or from a space shuttle, some have students

key in data that they have collected on a given phenomenon, and some input data through external probes connected to the students' computer, such as temperature gauges and heart rate monitors (these latter simulations are often called micro-computer-based laboratories). Simulations vary on whether they are designed for students to use individually, with colleagues, or with many students around the globe. Some simulations require that students work through the simulation according to a fixed sequence, some vary the sequence depending on students' prior responses, and some allow the students complete freedom in how the simulation is used. Simulations also vary on the form and degree of interactivity. One form of interaction has students practice previously taught knowledge and skills; a second form encourages students to explore, experiment, predict, and invent, and to infer new knowledge from their work; a third but uncommon form asks students to construct simulations to provoke systemic thinking about a given phenomenon.

Use of Simulations in Instruction

Simulations serve as enriched substitutes for written exercises in texts and workbooks. They can be used to prepare students for demanding laboratory experiments that might otherwise be unsafe or expensive. They can also be used as substitutes for laboratory work.

Most simulations are designed for individual student interaction, or for small groups of students sharing one computer. Web-based simulations also make possible, for the first time, the use of data input and control by thousands of students scattered across the globe.

A teacher, before a class, can demonstrate web-based simulations. That will require only one computer per class, but unless the class is quite small, an LCD projector will be needed so that all students can see the computer screen. This is generally considered the least preferable way of using simulations because it removes students from the direct interaction. However, the benefits to students can be enhanced by having the class decide on each move to be taken or by letting individual students take turns controlling the keyboard as the others look on.

Examples of Simulations for Mathematics and Science Instruction

The following are the best simulations that were found during a brief review of English language sites. Many of these sites require Shockwave, Flash, and sometimes other plug-ins. If your computer does not already have what is needed,

the site will notify you of that and link you to a site that provides a free download. Make sure to close down all other active applications on your machine before starting the download.

The "Mathforum" site offers early primary education "activities" in basic geometry and measurement. For each activity there are stated objectives, a manipulative exercise with materials widely available in schools and homes, a "technology activity" to be conducted with a colorful interactive simulation, and references to children's books that treat the same topic. This is an easy-to-use site for both teachers and students. <http://mathforum.com/varnelle/index.html>

"BBC Online Education" offers an all-purpose education site. It has many instructional aids, including some simulations, but the site is difficult to navigate. A click on "Schools" takes one to a page with resources organized by grade level, with links to various subjects. For instance, for the age 4-11 group, click on "MegaMaths," then on "World of Tables," then on "Pick a Number," then to any card shown, and then on "Patterns and Hints" to reach a dynamic multiplication table. "Table Tournament" provides a fast-paced multiplication tables game with captivating graphics that, for instance, require the users to answer multiplication problems quickly before a rolling bolder crashes into them. "Tell Us Your Top Tips" offers tips on doing multiplication quickly. <http://www.bbc.co.uk/education/home/>

"ExploreMath.com" offers a series of high school mathematics simulations, most of which show the relationship between equations and their corresponding two-dimensional graphs. The user can modify the equation and see how that affects the graph, or modify the graph and see how that alters the equation. This is one of the few simulations that permit the latter form of interaction. There is also a library of lesson plans that make use of the simulations. <http://www.exploremath.com>

University of Minnesota's "Geometry Center" offers several interactive simulations of college-level geometry. Generally the user specifies functions or coordinates, and then sees the geometric representation. The simulation includes hyperbolic triangles, Lorenz equations, projective conics, and Teichmuller navigation. These interactive components are in the two-fold link titled, "Interactive Web and Java Applications." There are brief instructions for using the simulations, but no instructional guides or lesson plans. This site also offers downloadable software and other resources for teachers of advanced geometry. Although the site is no longer being maintained, it remains functional. <http://www.geom.umn.edu>

The "Visual Calculus" site has an extensive set of visual resources to accompany a two-semester college course in cal-

culus. Some of the resources are Web-based interactive simulations and some are free downloadable simulation software that can be run from individual microcomputers. Ironically, many of the simulations are of the TI-85 and TI-86 graphing calculators. Short tutorials precede the visualizations. The professor who developed this site also has posted the syllabi for the courses that he teaches with these Web-based resources, so that other instructors can see how they are integrated with the course. <http://archives.math.utk.edu/visual.calculus>

The Children's Museum of Indianapolis offers a "Living in Space: Design a Space Station" site that starts the young user (about age 6-10) with a brief non-interactive simulation of a space shuttle launch. Then, if he/she is smart enough to click "Skip intro" just below the shuttle window, an interactive shuttle design simulation is presented. The user is asked to design a habitable space station, making decisions that draw upon an understanding of both human biology and the nature of space--about the air to be breathed, the amount of water needed, and the appropriate diet. If the user responds with an incorrect choice, he/she is nicely told why it is wrong and asked to answer again. This is a low-tech simulation using only linked pages of graphics, text, and links. <http://www.childrensmuseum.org/cosmicquest/index.html>

"ExploreScience.com" includes a substantial number of simulations about building blocks, mechanics, wave motion, electromagnetism, optics, astronomy, and life sciences. The mechanics simulations include those of two colliding masses, an inclined plane, and freefall. The user can change the variables and visually see what happens. There are no instructional guides or lesson plans to go with the simulations. <http://www.explorescience.com>

The "Annenberg Teachers' Lab" is intended to provide teachers with a deeper understanding of commonly taught mathematics and science concepts. Of the four posted labs, only the "Light" lab was functional when checked. It provides some instruction and then interactive simulations. There are brief instructions on how to use the simulation. Several questions are to be answered by use of the simulation, and then there are additional questions that ask for general principles and rules inferred from the simulation. While presented as a teacher preparation tool, students could also use the site. <http://www.learner.org/teacherslab>

Costs of Web-Based Simulations

There are many Web-based simulations that are currently available for free. That doesn't mean using them will be without costs. Their use requires one or more computers, perhaps an LCD projector, and Internet connection. Most of the simulations are currently in English. Countries using other languages of instruction have two options—they can contract with the developers to convert the English text, and sometimes audio, or they can develop their own simulations. The effort required of the latter should not be underestimated.

Despite these substantial costs, simulations can be cost-effective in developing countries under certain circumstances. That would be so if the simulations preclude the need to build, equip, and supply expensive laboratories; or when considerable numbers of computers with Internet connections are already present and underutilized.

Web-based simulations often cannot be downloaded to an individual microcomputer because they require frequent exchanges with the home server. Because of that, they are not well suited where Internet connections are slow, unreliable, or expensive. In those situations the better option is to license the simulations and install them on local area network server.

Selecting Web-Based Simulations

Several criteria should be considered when selecting Web-based simulations. The curriculum objectives and current student achievement of those objectives should be a major criterion by which simulations are selected. Simulations should address priority objectives that would not otherwise be well met. It is important that the simulations be neither too easy nor too difficult for most of the students using them. Some simulations require considerable time to work through, and others take only a few minutes. Simulations vary in their requirements for hardware (usually at least 64 megabytes of RAM and 200 kHz machines) and the needed browser software versions. The titles of simulations, and the promotional materials, do not always represent the simulation well; so the simulations should be tried out thoroughly by a few teachers and students before making large commitments to using them.

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